Cutting edge technology: knitting in the Early Modern era

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Abstract

New scientific evidence of trade in raw materials and finished goods for the knitted textile trade is emerging from a study of more than 100 extant knitted caps from the 16th century. These long-overlooked archaeological data are being re-excavated from museum archives for analysis in innovative ways. The caps are recorded in European collections as having been shipwrecked, deliberately concealed, preserved in peat bogs, or discarded as beyond use. Many were unearthed during construction work in cities, during building renovations or discovered on the seabed in far-flung locations across Europe – as far north as Norway and as far south as Croatia. Nevertheless, they show remarkable similarities in the materials used and methods of construction employed. A preliminary study recorded rudimentary measurements and identified some key patterns in the data, including a typology of early modern men's knitted caps. Initial results from more recent biomolecular investigative techniques including strontium isotope analysis, which compares soil samples with archaeological material, indicate the land from which the knitted yarn was sourced. Contemporary evidence from documentary sources suggests labour for knitting the caps was organised in proto-industrial settings. Import/export accounts at northern European ports demonstrate how far knitted caps travelled from their places of production to potential purchasers. The knitted caps represent an astonishing body of evidence for trade in ordinary men's clothing given the paucity of extant garments available from the era and demonstrate the swift expansion of knitting as a key technological innovation of the 16th century.

Keywords: textile, knit, polynomial texture map, ct-scan, x-ray, proteomics, isotopes, multidisciplinary

Introduction

There is now a wide variety of innovative scientific tools available for the study of ancient and historical organic materials. These draw on pioneering work in medicine, industry and forensics to produce new findings from extant objects. Raw materials including wool, hair, flax, leather, bone, teeth and feathers are revealing revolutionary insights for scholars working in the humanities. These methods are particularly exciting given the enormous number of garments in long-established museum collections which is tentatively dated, lacks a recorded provenance or archaeological context, and with few or no details of previous conservation treatments or storage conditions over many years. Newly-applied analytical techniques offer the possibility of putting these objects back into context with clues to their era of manufacture, place of origin, and subsequent stories as museum artefacts.

Many of the analytical tests discussed here have yielded fruitful results when applied to material which has languished unnoticed for more than a century. A prime example is the Danish Huldremose woman, who spent much of her life after excavation in 1879 as a forgotten curiosity until recent re-examination revealed a great deal about her wardrobe and, in turn, the society in which she lived and died.[1,2] Much of the evidence presented here relies – as with the Huldremose clothing – on the application of scientific techniques to ancient or archaeological material. Whether these techniques are equally revealing about clothing from later eras remains to be seen. This is the inspiration for KEME, a project focusing on early modern knitted material which is typical of the data about dress awaiting re-excavation from museum storage.[3]

Image 1: *Simon George*, Hans Holbein, c1535, The Royal Collection, RCIN 912208.

There are more than 100 knitted caps of the kind worn by ordinary people in the 16th century in museum collections (Image 1). These are recorded as having been shipwrecked, deliberately concealed, preserved in peat bogs, or discarded as beyond use. A previous study of the caps suggested that despite the geographical spread of their discoveries, they present remarkable

[1]K. Frei, I. Skals, M. Gleba, & H. Lyngstrøm, "The Huldremose Iron Age textiles, Denmark: an attempt to define their provenance applying the strontium isotope system," *Journal of Archaeological Science*, Vol. 36, (2009), 1965-1971.
[2]K. Frei, U. Mannering, K. Kristiansen, M. Allentoft, A. Wilson, I. Skals, S. Tridico, M-L Nosch, E. Willerlev, L. Clarke, & R. Frei, "Tracing the dynamic life story of a Bronze Age Female," *Scientific Reports*, (2015), Vol. 5, 10431, 1-7.
[3] J. Malcolm-Davies & H. Davidson, (2015) "'He is of no account … if he have not a velvet or taffeta hat': a survey of 16th century knitted caps," K. Grömer & Pritchard, F – eds., *Aspects of the Design, Production and Use of Textiles and Clothing from the Bronze Age to the Early Modern Era, NESAT XII* (North European Symposium for Archaeological Textiles), Hallstatt, Austria, May 2014.

similarities in their materials and manufacture.[4] The knitted caps have, in most cases, doubtful provenance and little is known about the conditions in which they have been kept (Image 2). They are representative of much material held in museums which may benefit from a new research perspective. KEME's aim is to provide a benchmark for the usefulness of various scientific techniques to the study of textiles in museum collections. The knitted caps present a range of similar items from different places, discovered at different times and under different conditions, and kept in a variety of environments. They offer an opportunity for comparable data to be extracted from which some principles of good practice may emerge.

Implications of scientific testing

The scientific analyses available for textiles fall into three broad categories, which are differentiated by the extent to which original items must be handled or altered for the tests to be performed. These are: non-invasive tests, invasive tests and destructive tests.

Image 2: Knitted wool cap with neckflap and separate red lining, 1500-1600, purchased from the estate of John Seymour Lucas in 1913 after excavation in Finsbury, possibly in 1902. Inventory number A6346. © Museum of London.

Non-invasive analysis

Specialist photography offers new ways of presenting artefacts than conventional digital representation. Polynomial texture mapping (PTM) is a technique for illustrating surface detail and conveying its texture. A series of relatively simple conventional photographs taken around a static object are used to re-light it as though from many different angles simultaneously using reflective transformation imaging (RTI) software, which is freely available for non-commercial

[4] Malcolm-Davies & Davidson, op cit.

projects.[5] PTM has been used to represent knitted items online at The National Archives.[6] Relatively inexpensive software is also available for "stitching" multiple conventional photographs into a 360 degree view of an object. The knitted caps in the KEME project have been photographed to investigate the feasibility of illustrating them online as high-quality, three-dimensional images with sophisticated representations of their surfaces.

Invasive analysis

X-rays have the capacity to change the structure of textiles by, for example, damaging any DNA that may be available for analysis. They have been used to study a collection of 35 prehistoric yucca sandals found in Antelope Cave, Arizona (United States). The internal features and the toe and heel shaping are hidden inside the tightly woven objects. Radiography revealed new details about their construction, including splicing techniques and the spin and twist of the cords used in the warp.[7] X-ray photography has likewise revealed hidden elements of 17th century clothing such as the number of layers in its construction and the stitches within the layers.[8] X-rays of a knitted 18th century stocking featuring metal thread embroidery and evidence of wear and repair has enabled a close understanding of its structure and construction.[9]

Another technique employing x-rays is computed tomography (CAT-scanning or micro-CT scanning), which scans cross sections of objects revealing their interior structure. These can be used to build three-dimensional digital models. CT scans make it possible to examine the layers of a dressed body or figure without disturbing their structure. CT-scanning has contributed to the virtual unrolling of a charred, crushed scroll probably dating to 300 AD and the reconstruction of the writing on it.[10] This success with skin parchment suggests potential for scanning and understanding folded or rolled textiles too fragile to be manipulated and for examining layers of clothes packed in boxes, bags, furniture or museum storage before handling.

X- ray imaging, tomography and digital reconstructions of the knitted caps will assist the diagnosis of how they are constructed – in particular, how the various elements are joined together, where seams and other features are hidden inside. There is also the potential for the visualisation and reconstruction of the textile's surface structure.[11] CT-scans of modern samples

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[5] T. Goskar & G. Earl, "Polynomial texture mapping for archaeologists," *British Archaeology* (March/April, 2010), 28-29.
[6] D. Eastop, "Texture mapping: part two," *Exploring the BT design register: representing sensory experience*, The National Archives, 18 April, 2013, available at: http://blog.nationalarchives.gov.uk/blog/texture-mapping-part-two/#more-8511 (last accessed 5 December 2016).
[7] D. Yoder, "The use of 'soft' X-ray radiography in determining hidden construction characteristics in fiber sandals," *Journal of Archaeological Science*, Vol. 35 (2008), 316-321.
[8] J. Tiramani & S. North, *Seventeenth-Century Women's Dress Patterns*, (London: Victoria & Albert Museum, 2015).
[9] S. O'Connor, M. Brooks, & J. Sheppard, "X-radiography of a knitted silk stocking with metal thread embroidery," O'Connor, S & Brooks, M. eds., *X-Radiography of Textiles, Dress and Related Objects* (Oxford: Elsevier, 2007).
[10] W. Seales, C. Parker, M. Segal, E. Tov, P. Shor, & Y. Porath, "From damage to discovery via virtual unwrapping: Reading the scroll from En-Gedi," *Science Advances*, Vol. 2 (2016), 1-9.
[11] S. Zhao, W. Jakob, S. Marschner, & K. Bala, "Building Volumetric Appearance Models of Fabric using Micro CT Imaging," SIGGRAPH 2011 Proceedings, available at https://shuangz.com/projects/ctcloth-sg11/ctcloth-sg11.pdf (last accessed 21 February 2016).

of knitted and fulled fabric has virtually stripped away the raised nap created by fulling to reveal the hidden loops of knitting underneath.

Many scientific tests rely on taking samples, and although these are not destroyed during investigation, their removal causes damage to the original object. Sample sizes vary according to the method of analysis. Material reported as removed from archaeological and historical artefacts includes 2x2mm from skin garments,[12] 5x5mm from wool and skin items,[13] 10x10mm from medieval fabric,[14] and 100 single fibres of early modern wool.[15,16] Very few studies describe the actual process of selecting and removing these, although there are a few notable exceptions, including a description of samples ranging from 0.2 to 1.5cm in length taken from Italian and Austrian textile fragments dating to the Late Bronze Age.[17]

Destructive analysis

Destructive tests require material to be removed from a garment, which is usually exhausted during analysis.

Proteomics

Proteomics is the study of proteins, which are built of amino acids. These are analysed via mass spectrometry, which breaks the protein down to produce a profile showing which peptides (formed by the amino acids) are present and in what quantities. This profile is compared to reference material which permits identification of the source of the proteins.

Skins and furs have been successfully identified using proteomics because they are particularly rich sources of proteins suitable for peptide sequencing (such as collagen and keratin). The traditional method of identifying hides is via microscopy but this is a highly subjective activity, especially for garments made from degraded materials in which only a selection of potentially unrepresentative fibres may be preserved. Danish hide capes from 920 BC to AD 775 were previously identified as sheep, goat, cow, otter, wolf and deerskin using these methods. However, the references used for comparison were based on modern animal fibres, which do not necessarily have the same characteristics as archaeological or historical material due to animal husbandry techniques such as selective breeding.[18] Comparison of two microscopic methods

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[12] L. Brandt, A. Schmidt, U. Mannering, M. Sarret, C. Kelstrup, "Species Identification of Archaeological Skin Objects from Danish Bogs: Comparison between Mass Spectrometry-Based Peptide Sequencing and Microscopy-Based Methods," *PLoS ONE,* Vol. 9, No. 9 (2014), e106875. doi:10.1371/journal.pone.0106875.
[13] A. Rast-Eicher, & L. Bender Jørgensen, "Sheep wool in Bronze and Iron Age Europe," *Journal of Archaeological Science,* Vol. 40, (2015), 1224–1241.
[14] M. Fedi, A. Cartocci, F. Taccetti, & P. Mando, "AMS radiocarbon dating of medieval textile relics: The frocks and the pillow of St Francis of Assisi," *Nuclear Instruments and Methods in Physics Research B*, Vol. 266, (2008), 2251–2254.
[15] M. Ryder, "Wools from textiles in the *Wary* a Seventeenth-century Swedish Warship," *Journal of Archaeological Science*, Vol. 10, (1983), 259-343.
[16] M. Ryder, "Wools from textiles in the *Mary Rose* a Sixteenth-century English Warship," *Journal of Archaeological Science*, Vol. 11, (1984), 337-343.
[17] M. Gleba, "From textiles to sheep: investigating wool fibre development in pre-Roman Italy using scanning electron microscopy (SEM)," *Journal of Archaeological Science,* Vol. 39 (2012), 3646.
[18] Brandt et al, 2014, op cit.

(light microscopy in combination with macroscopial observation and scanning electron microscopy) with proteomic investigation showed agreement between all three for six of the 12 hide garments. For the other six, the two microscopic methods disagreed as to the identity of the animal and in four of these cases the peptide sequencing agreed with one or other of the microscopic methods. Sheepskin was generally agreed upon but horse, goat and cow skin were particularly problematic to distinguish. Further scrutiny of the peptides permitted secure diagnosis for each garment and even identified one cow hide as that of a foetal or post-natal calf (up to three months old) owing to the presence of haemoglobin specific to that phase of life.[19] Clothes from about 3300 BC worn by the Neolithic man known as Oetzi, who was discovered in the Tyrolean ice in 1991, have also been investigated via proteomics. The proteins showed that he wore a range of furs and hides. His shoe vamp was red deerskin, his leggings were goatskin and grey wolfskin, domestic dog or European red fox, and his shoe sole was cow hide. There was sheep and goat skin in his coat, and his fur cap was from a carnivore species – either brown bear or a canid.[20]

Wool is hair fibre and therefore high in protein, which makes it suitable for peptide sequencing. However, the usefulness of proteomics to the study of early modern knitted material may be limited. If conventional microscopy can confirm without doubt that the fibre is wool, there is not much more that may be discovered through protein analysis. Current reference material does not extend to proteomic spectra for specific sheep breeds and, even if these were available for modern sheep, they would not be relevant for historical material.

Isotopic tracing

Strontium is a trace element in rock, water and soil. It passes to plants as they grow and into animals as they feed on them. One of the natural isotopes of strontium is formed by the radioactive decay of rubidium and accumulates slowly over time. It is usually expressed as a ratio of one of the other more stable strontium isotopes as ^{87}SR/^{86}SR. Older rocks such as granite have high value ratios, whereas newer rocks have lower values. Landscapes are composed of different distributions of rocks and therefore have identifiable, if not unique, profiles. Items made from plant or animal products in the past can be interrogated for their strontium isotopic value, which is then compared to reference ratios to determine likely source localities.[21]

The remains of a high-status female of about 16 to 18 years old were excavated in 1921 near Egtved, a Danish village. Her wool and hide garments were well preserved, as was her oak coffin, which was dated to approximately 3,400 years ago by dendrochronology. A recent study investigated her wool tunic, skirt, belt, foot wrappers, and her oxhide wrap (among other items). The results showed that all of these were made from raw materials originating outside what is present-day Denmark. Comparison of the strontium isotope signature with neighbouring

[19] Ibid.
[20] K. Hollemeyer, W. Altmeyer, E. Heinzle, & C. Pitra, "Matrix-assisted laser desorption/ionization time-of-flight mass spectrometry combined with multidimensional scaling, binary hierarchical cluster tree and selected diagnostic masses improves species identification of Neolithic keratin sequences from furs of the Tyrolean Iceman Oetzi," *Rapid Communication in Mass Spectrometry*, Vol. 26 (2012), 1735–1745.
[21] N. Slovak, & A. Paytan, (2011) "Applications of Sr Isotopes in Archaeology," M. Baskaran – ed., *Handbook of Environmental Isotope Geochemistry, Advances in Isotope Geochemistry* (Berlin & Heidelberg: Springer-Verlag

landscapes suggested the south-west of Germany and the Black Forest in particular as a likely source locality, although this is not the only European match available.[22]

Other isotope tracing methods have used triangulated data to profile the geographical signature of a region in terms of carbon[13], nitrogen[15] and hydrogen[2]. Archaeological material from three geographical areas (Iceland, north east England and Frisia in Germany) was identified as local or non-local with reference to the isotopic profiles of modern sheep. The study showed that keratin from modern and archaeological sheep, and bone collagen from the latter, had matching geographical signatures. These geographical profiles are dependent on differences in climate, environment and animal husbandry in the three locations.[23] The study included a sample from a fragment of knitting found in Newcastle and dated by archaeological context to the first half of the 15th century. Previous interpretation suggested it was likely to be from Spain or France since its fine fleece and the kermes with which it was dyed was thought to be little known this early in the United Kingdom.[24] However, the isotopic profile of the sample was consistent with a British provenance or another place of origin "with a climate and environment relatively similar".[25] Isotopic profiling of the knitted caps may produce a map of likely provenance indicating whether there was a unique centre of production or numerous places where the raw materials were produced.

Recommendations

A protocol for the scientific investigation of archaeological textiles and potentially of historic dress is emerging. A priority test sequence, which ensures one type of analysis does not prejudice another and whereby the detection of certain chemical elements avoids analysis known to be inhibited by them, would be desirable. A sampling strategy, which minimises the material required and ensures appropriate recording of the process, is also a requirement for future good practice. Careful communication is necessary between experts crossing boundaries between the arts, humanities and sciences. This calls for new ways of working in pragmatic multidisciplinary teams.[26] There is also a need to integrate the empirical results promised by scientific enquiry into the interpretive framework offered by traditional contextual studies to avoid errors caused by the dazzle of new data.[27,28] Textile archaeology has blazed a trail for innovative cross-cultural

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[22] Frei et al), 2015, op cit.

[23] I. Von Holstein, P. Walton Rogers, O. Craig, K. Penkman, J. Newton, M. Collins, "Provenancing Archaeological Wool Textiles from Medieval Northern Europe by Light Stable Isotope Analysis (δ13C, δ15N, δ2H)," PLoS ONE 11, 10, available at http://eprints.whiterose.ac.uk/106674/1/journal.pone.0162330.pdf (last accessed 5 December 2016).

[24] P. Walton, "The textiles," Harbottle, P & Ellison, M – eds., *An excavation in the castle ditch, Newcastle upon Tyne. Archaeologia Aeliana*, 5th Series Vol. 9 (1981), 190-228.

[25] Von Holstein et al, op cit.

[26] A. Pollard, & P. Bray, "A Bicycle Made for Two? The Integration of Scientific Techniques into Archaeological Interpretation," *Annual Review of Anthropology*, Vol. 36 (2007), 245–259.

[27] T. Sørensen, "In Praise of Vagueness: Uncertainty, ambiguity and archaeological methodology," *Journal of Archaeological Method and Theory*, Vol. 23, No. 2 (2016), 741-763.

[28] M. Harlow, & M-L Nosch, "Weaving the threads: Methodologies in textile and dress research for the Greek and Roman World: the state of the art and the case for interdisciplinarity," Harlow, M & Marie-Nosch, M-L – eds., *Greek and Roman textiles and dress: an interdisciplinary anthology*, Ancient Textiles Series, 19, (Oxford: Oxbow Books, 2014), 1-33.

academic collaboration.[29] Dress history, and the KEME material in particular, offers similarly fertile ground for new paths leading to new knowledge.

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